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Automatic Toll collection system using GNSS signal

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Abstract— ***Toll collection system for road user to control traffic and its resulting pollution, as well as revenue sources for reinvestment in the road infrastructure. Among them, Automatic toll collection (ATC) systems based on user positions estimated with Global Navigation Satellite Systems (GNSS) are particularly attractive due to their flexibility and reduced roadside infrastructure in comparison to other systems such as tollbooths. Because GNSS positioning may be perturbed by different errors and failures, ATC system, as liability critical applications, should monitor the integrity of GNSS signals in order to limit the use of faulty positions and the consequent charging errors. The integrity-monitoring systems have been originally designed for civil aviation; hence, they need to be adapted to the ATC requirements. This paper studies the use of receiver autonomous integrity monitoring (RAIM), which are algorithms run within the GNSS receiver and, therefore, are easier to tune to ATC needs than other systems based on external information. The weighted least squares residual RAIM used in civil aviation is analyzed, and an algorithm modification for ATC is proposed. Simulations demonstrate that the proposed RAIM algorithm has a superior level of availability over civil-aviation-based RAIM procedures, particularly in urban environments.***

Keywords— ATC (Automatic Toll Collection System), GNSS (Global Navigation Satellite System), GPS (Global Positioning System), RAIM (Receiver Autonomous Integrity Monitoring)

I. INTRODUCTION

This Integrity of Global Navigation Satellite Systems (GNSS) is defined as a measure of the trust that can be placed in the correctness of the information supplied by the navigation system [1]. The concept of GNSS integrity was originally developed in the civil aviation framework as part of the International Civil Aviation Organization (ICAO) requirements for using GNSS in the Communications, Navigation, and Surveillance/Air Traffic Management system. In particular, civil aviation standards specify a set of minimum accuracy, availability, integrity, and continuity performance on the GNSS signal-in-space for each operation and phase of flight.

Two types of applications need GNSS integrity, i.e., safety-of-life applications, in which undetected navigation errors may endanger life, and liability critical applications, in which positioning errors may have negative legal or economic consequences. A number of integrity-driven positioning applications have vehicular or pedestrian users and take place in urban and rural environments. A few examples of these applications are electronic toll collection, train control, dangerous or valuable goods transport survey, and emergency calls. Each application has its own integrity constraints and needs an integrity-monitoring technique adapted to its specifications.

This paper focuses on ATC systems in urban and rural environments based on GNSS positioning. GNSS-based ATC schemes are particularly interesting because they are free-flow (pay-as- you-drive) highly flexible systems with a reduced quantity of roadside infrastructure. Moreover, satellite navigation is, together with 5.8-GHz microwave and GSM-GPRS communication systems, one of the technologies. GNSS-based ATC systems are liability-critical applications because excessive and uncontrolled positioning errors may lead to incorrect toll invoices. The act of levying a toll lower than it should be is denoted as undercharging and implies a loss of revenue, whereas the act of levying a toll higher than it should be is known as overcharging and may originate user claims. Thus, ATC specifications should bind the maximum acceptable rate of undercharging and overcharging errors in order to assure the quality of service to both users and the toll operator. For this reason, GNSS integrity monitoring is a key element of ATC systems, which assures that positioning errors are below the specified limits, detecting unacceptably large errors.

II. GNSS-BASED ATC SYSTEMS

The discrete road links charging toll scheme defined in the ISO standard [13] is studied. The geo-fencing approach is followed, in which the tolled road network is split into segments defined by virtual perimeters. The areas within the perimeters are denoted geo-objects and constitute the basic charging units, that is, users are charged the price associated to a geo-object whenever they are detected inside it. Each geo-object's fee is individually set and can be designed according to different factors such as the user category, the time of the day, or the traffic state. Moreover, distance-based charge is possible when geo objects are defined as road portions between intersections, with only one entrance and one exit. Geo-fencing is an appropriate approach for GNSS-based ATC applications that allows highly flexible systems with a low number of roadside infrastructures.

The main task of the ATC system is to decide whether a user has driven through a road segment or not and charge him if he has. This decision, which is known as geo-object recognition, can be taken as a function of the number of user positions lying inside the geo-object boundaries.

In order to bind the maximum rate of erroneous geo-object recognitions (i.e., erroneously charged segments), only positions declared valid by the integrity-monitoring system are used. Moreover, only independent positions are taken to eliminate the effects of the positioning error temporal correlation. In this context, two position estimates are independent when they produce independent integrity-monitoring outputs. The correlation time depends on the GNSS receiver type and other constraints within the local environment.

The integrity-monitoring systems have been originally designed to meet the civil aviation requirements; hence, they need to be adapted to the ATC specifications. From the various possible integrity-monitoring systems, this work studies receiver autonomous integrity monitoring (RAIM), which are algorithms run within the GNSS receiver that monitor integrity due to redundant pseudo range measurements. Since RAIM algorithms, as opposed to GBAS or SBAS, do not rely on external information, they can be easily adapted to the ATC requirements and to the multi frequency multi constellation case. This paper considers the use of SBAS corrections but not of its integrity service because it has been designed mainly to assure the civil aviation requirements. Only the integrity of horizontal positioning is required to be monitored for ATC application. For each estimated position, RAIM provides a horizontal protection level (HPL), which is defined as a circular area centered at the user real position that is assured to contain the estimated position with a probability that is equal to or higher than (1 – PMD), where the maximum allowed probability of missed detection PMD is a design parameter. The horizontal alert limit (HAL) is the maximum allowed HPL and depends on the road network topography and can beat as half the distance between roads [14].

A. *Algorithm Design*

The WLSR RAIM considers the following linear pseudo range measurement model:

$\Delta Y = H \cdot \Delta X + E$

Where, ΔY [Ns × 1] is the linearized measured pseudo range
Vector, H [Ns × Nu] is the observation matrix, ΔX[Nu × 1] is
The linearized navigation state vector, and E [Ns × 1] is the pseudo range error vector.
Ns is the number of pseudo ranges, and Nu is the number of unknowns in ΔX.

Two possible pseudo range error scenarios are assumed, namely, fault-free and faulty. In the fault-free case, pseudo range measurements are disturbed only by nominal errors, modeled as zero-mean independent Gaussian distributions with covariance matrix Σ. In the faulty case, apart from nominal errors, there is one biased pseudo range measurement.

B. *Algorithm Implementation at the GNSS Receiver*

The algorithm run within the receiver consists of two modules, i.e., the RAIM availability check and the Fault detection (FD; see Fig. 2). The FD could be replaced by a Fault Detection and Exclusion module. First, at each epoch, the slope of each pseudo range measurement is calculated due to the observation matrix and the nominal error covariance matrix. The HPL is computed afterward with the maximum slope and the corresponding chi-squared non centrality parameter. If the HPL exceeds the HAL, RAIM is not available because it cannot monitor integrity with the required HAL, i.e., PMD and PFA. In this case, the integrity cannot be monitored; hence, the estimated position is not valid for its use in ATC.

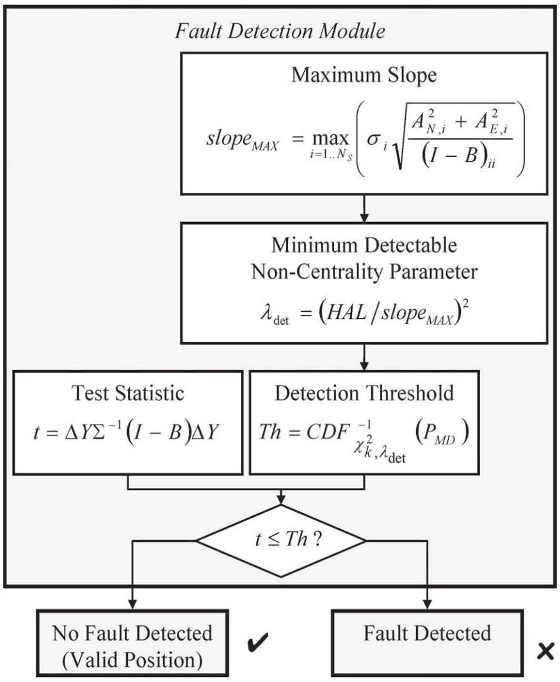

Fig.1. WLSR RAIM algorithm with fault detection capabilities run within the GNSS receiver.

III. WLSR RAIM ALGORITHM FOR ATC

The WLSR RAIM for ETC is designed to provide the fault-free case, the lowest probability of false alarm PFA that meets the required PMD and HAL. The algorithm constantly provides an HPL equal to the HAL. For this reason, the actual probability of detection probability of positioning failures larger than the HAL is less conservative than in the original algorithm. Therefore, the modified WLSR RAIM minimizes the probability of false detection, at the expense of a less conservative probability of undetected positioning failures. High maximum slopes due to bad user/satellite geometries result in a high HPL in the civil aviation RAIM procedure and in high PFA in the modified algorithm. This means that positions rejected by the civil aviation algorithm due to RAIM unavailability can be monitored with the new algorithm at the cost of increasing PFA. Probability of rejecting a fault-free position for both RAIM procedures with one redundant pseudo range measurement (k = 1), as a function of the ratio HAL/slopeMAX. Let us remember that a position is declared valid when the RAIM is available and does not detect a failure.

The WLSR RAIM described in this section is to maximize the number of valid positions in the fault-free scenario. The modified RAIM is designed to assure a constant PMD in order to set a known maximum probability that a faulty position inside the geo-object is declared valid when the user is actually outside it.

$$\lambda_{\mathrm{det}} \leq \mathrm{HAL}/\mathrm{slope}_{MAX}$$

A. Navigation System performance

This section presents the navigation system performance; the final toll charging performance should include other possible failures such as geo-object database errors. The WLSR RAIM performance depends on the design parameters (HAL, PMD, and, in the classic algorithm, PFA) and on the maximum slope, which, in turn, depends on the environment, i.e., the user/satellite geometry. The RAIM performance in rural and urban environments has been obtained via simulations. The simulated scenario consists of a user moving at a constant velocity of 50 km/h along the axis of a 20-m-wide straight street. Buildings are statistically generated at both sides of the street as in Table I, separated by a gap with a probability of 10−1. The nominal 24-satellite GPS and 27-satellite Galileo constellations are simulated and only line-of-sight satellites with an elevation angle over 5° are assumed to be received by the user. The simulation length is set to 72 h to cover approximately all possible GPS and Galileo satellite ground track combinations. Data are sampled every second. Three GNSS receivers are studied. A single-frequency GPS L1 C/A with a wideband front-end of 16 MHz augmented with SBAS corrections, a single-frequency dual-constellation GPS and Galileo L1/E1 BOC(1,1) with a 4-MHz front-end filter augmented with SBAS corrections, and a dual-frequency GPS and Galileo L1/E1MBOC and L5/E5a BPSK(10) with 14- and 20-MHz front-end filters, respectively. The first configuration will give the performance of current high performance receivers and the GPS and Galileo configurations with modernized signals represent the performance attainable in a near future. In the dual- installation case, a modernized SBAS capable of correcting Galileo signals is assumed. Various charging metrics can be used to define the ATC required performance; however, numerical values of these metrics are not standardized.

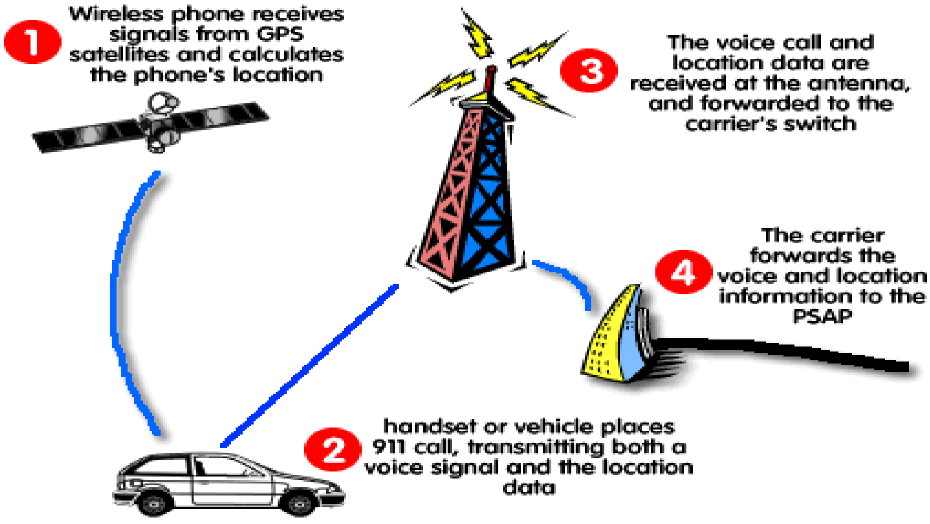

Fig.2. System model.

A pseudo range nominal measurement model suitable for integrity applications in urban environments is used. The pseudo range error is calculated as the result of various independent error sources, namely, ionosphere and troposphere delays, tracking loop errors, multipath and ephemeris, and satellite clock errors. The model is summarized as follows. The ionosphere residual error model is that of the civil aviation standards for single frequency GPS and SBAS and zero for dual-frequency users.

Finally, the GNSS are assumed to be sufficiently modernized to assure ephemeris and satellite clock nominal errors with a standard deviation of 85 cm. The total pseudo range error model is a zero-mean Gaussian distribution with the standard deviation (σPSR) in Fig.3

IV. CONCLUSION

GNSS-based ATC systems need to monitor the positioning integrity in order to control the effects of undercharging and overcharging due to positioning failures. With this purpose, two RAIM algorithms have been studied, i.e., the WLSR AIM used in civil aviation and a modified algorithm that, maintaining PMD, maximizes the number of valid positions (that is, available RAIM and no fault detected). The aim of the proposed algorithm is to decrease the rate of undercharging in reduced-visibility scenarios such as urban environments, assuring the same maximum allowed overcharging risk as the civil aviation RAIM procedure. This objective has been demonstrated by simulations. The improvement of dual constellation receivers in urban environments, which provide undercharging rates several orders of magnitude lower than GPS-only ones, has been also shown. The proposed design with variable PFA and a fixed HPL can be extended to other existing RAIM algorithms.

REFERENCES

[1] Daniel Salós, Anaïs Martineau, Christophe Macabiau, Bernard Bonhoure, and Damien Kubrak, “Receiver Autonomous Integrity Monitoring of GNSS Signals for Electronic Toll Collection”, in IEEE 1524-9050

[2] R. Vargic, M. Buncak, and J. Kacur, “On self-similarity in service triggering in NGN networks using satellite based tolling systems,” in *Proc. ELMAR*, Sep. 14–16, 2011, pp. 183–186.

[3] N. R. Velaga, M. A. Quddus, A. L. Bristow, and Y. Zheng, “Map-aided integrity monitoring of a land vehicle navigation system,” *IEEE Trans Intell. Transp. Syst.*, vol. 13, no. 2, pp. 848–858, Jun. 2012.

[4] R. Toledo-Moreo, D. Betaille, and F. Peyret, “Lane-level integrity provision for navigation and map matching with GNSS, dead reckoning, and enhanced maps,” *IEEE Trans. Intell. Transp. Syst.*, vol. 11, no. 1, pp. 100–112, Mar. 2010.

[5] R. Toledo-Moreo, M. A. Zamora-Izquierdo, B. Ubeda-Miarro, and A. F. Gomez-Skarmeta, “High-integrity IMM-EKF-based road vehicle navigation with low-cost GPS/SBAS/INS,” *IEEE Trans. Intell. Transp. Syst.*, vol. 8, no. 3, pp. 491–511, Sep. 2007.

[6] F. van Graas and J. L. Farrell, “Baseline fault detection and exclusion algorithm,” in *Proc. 49th Annu. Meet. Inst. Navig.*, Cambridge,MA, USA, Jun. 1993, pp. 413–420.

[7] International Organization for Standardization (ISO), Geneva,Switzerland, “Electronic Fee Collection—Charging Performance—Part 1: Metrics” ISO/TS 17444-1, First Edition, 2012